CHAPTER 10

An Ensemble Effort

Mission operations are the ensemble of actions to plan and execute the launch and subsequent activities of a spacecraft, including data return. And since that data flow is divided into uplink and downlink, operations processes also fall into these two categories. Uplink encompasses planning mission activities; developing and radiating instrument and spacecraft commands, and execution of those commands. Downlink encompasses data collection; transmission to the ground, and data processing and analysis for system performance evaluation and science studies.

General Mission Operations

Mission operations involve complex interactions among people, computers, electronics, and even heavy machinery (at NASA's Deep Space Network antenna sites). Planning for mission "ops" begins with the conception of the mission itself, and involves assumptions about the frequency of communication with the spacecraft and data transfer rates and volumes. These, in turn, drive the design of the spacecraft hardware and software and of the ground system that will be manipulating the spacecraft during its interplanetary cruise and mission operations phases.

"Aces," as mission controllers are known, provide round-the-clock monitoring of deep space exploration missions such as Cassini–Huygens.

Sequence Planning

After basic design decisions have been made, their effects on day-to-day and long-term operations are considered, and a system is developed to enable spacecraft engineering, health and safety requirements and science data acquisition requirements to be met. The period of mission operations, starting shortly after launch, is divided into a series of intervals. These intervals may be constrained by engineering requirements (e.g., limitations on available spacecraft memory), mission events (e.g., a planetary flyby), flight rules (e.g., the spacecraft must have communications with the ground every 240 hours) or other constraints.

A "sequence" is prepared for each planning interval. The sequence is a series of computer commands that tells the spacecraft and its engineering and science subsystems what to do and when. These commands cover everything from the mundane, such as turning a heater on, to the sublime, such as aiming the camera and taking a sequence of approach images to make into a movie.

Uplink and Downlink

Most of the human interaction occurs at the beginning of sequence planning, when the push-pull of spacecraft engineering requirements and science measurement requirements and desires must be resolved. (Note that the push-pull of competing science requests must have been resolved first.) After what may be long hours of negotiations, the interests of all the concerned parties are met (more or less) and the actual work of sequence preparation can begin. This involves first generating human-readable commands (for proofreading purposes) and then converting them into the computer code words that the spacecraft can understand. The computer codes are then packaged into radio-transmissible "tones," instructions are given to the antenna on where to point, and the sequence is radiated to the spacecraft. The transmission is received and decoded by the spacecraft, which sends an acknowledgment and executes the commands. This portion of mission operations is referred to as uplink.

Downlink is what follows. In the course of executing the commands, both engineering subsystems and science instruments generate data that are often stored on the spacecraft for a while before they are coded and packaged for transmission to the ground as telemetry. On Earth, the data are decoded and forwarded to the engineering and science teams concerned with those particular activities on the spacecraft. The data are analyzed and engineering reports and science publications are generated for dissemination to their respective communities.

Signals Through Space

None of this happens instantaneously nor easily. Electromagnetic radiation — whether it is visible light with wavelengths in the range of 400 to 700 nanometers (400–700 billionths of a meter) or radio waves with wavelengths from 1 millimeter to 30 kilometers or longer (frequencies of 300 gigahertz to 10 kilohertz or lower) — take time to travel through space. The velocity of electromagnetic radiation in a vacuum is 299,792 kilometers per second. One-way light-times in excess of a few seconds (the equivalent distance to the Moon is about 1.3 seconds) make "joysticking" the spacecraft impractical. While provision is made for realtime commands, especially planned ones and those needed in response to emergencies, preplanned sequences are almost always used for commanding the spacecraft.

The amount of electromagnetic radiation (emitted by a point source) passing through a unit area decreases as the square of the distance. Thus, a spacecraft twice as far as Earth is from the Sun receives only one-fourth of the light and heat that it would receive at Earth's distance.

What is true of light and heat is true of radio transmissions as well, and it affects how telecommunications are accomplished. The radio transmitters and receivers on the ground and on the spacecraft are equipped with paraboloidal antennas that direct transmissions to the receiver and concentrate received radio energy, maximizing signal to the preamplifier–receiver–amplifier chain.

Large antennas are a necessity. While a commercial radio station may generate as much as 50,000 watts in its signal to your car radio a few tens or hundreds of kilometers away, a spacecraft typically has only a 20-watt transmitter that must reliably send signals over hundreds of millions or billions of kilometers across the solar system.

Spacecraft communications are typically accomplished using radio frequencies in S-band (2–4 gigahertz) or X-band (7–12 gigahertz). Some radio science measurements made with a spacecraft — for example, tests of Einstein's general theory of relativity — are made in K_a-band (32–34 gigahertz). (Radio astronomical observations from the ground and from spacecraft are made across a wide region of the spectrum.)

A Worldwide Effort

Cassini operations involve numerous people at many sites around the world. Careful coordination of the efforts of the science, engineering, planning, navigation and sequencing teams will permit the Orbiter and Probe to return a cache of scientific data on Saturn and its environs that will increase our understanding manyfold and allow scientists many years of additional study after the end of the mission.

Cassini–Huygens Operations

The purpose of Cassini–Huygens mission operations is to launch an instrumented spacecraft to orbit Saturn and deliver a Probe to Titan in order to accomplish primary scientific objectives. The program is a joint undertaking among NASA, the European Space Agency (ESA) and the Italian space agency, Agenzia Spaziale Italiana (ASI).

Mission Description

Cassini will be launched aboard a Titan IVB / Centaur launch vehicle with Solid Rocket Motor Upgrades and injected into a 6.7-year trajectory to

PLANETARY MISSION OPERATIONS
THE JPL WAY

Function	Primary Activities
Mission Planning	Generate a mission plan and mission phase plans. Generate mission and flight rules and constraints.
Integrated Sequence Development	Generate detailed timelines of activities. Generate integrated files of valid commands. Generate sequence and realtime command loads for radiation to the spacecraft.
Mission Control	Configure and control the ground system. Monitor in real time the spacecraft's and payload's activities, health and safety.
Navigation	Predict and reconstruct the spacecraft's trajectory. Design maneuvers to correct the trajectory to achieve mission objectives.
Spacecraft Analysis and Sequence Input Development	Plan, design and integrate engineering activities. Maintain the health and safety of the spacecraft through non-realtime analyses and anomaly identification and resolution.
Payload Analysis and Sequence Input Development	Generate a science operations plan. Design and integrate instrument observations. Maintain the health and safety of the payload through non-realtime analyses and anomaly identification and resolution.
Science Processing	Generate and archive processed data in support of payload analysis and for the purpose of scientific research.
Database Management	Provide throughout the mission realtime accessible engineering and science telemetry and ancillary data for non-realtime spacecraft and instruments analyses.
Data Acquisition	Acquire the downlink signal. Generate Doppler and ranging tracking data. Extract and digitize the original information from the modulated subcarrier of the radio signal. Eliminate bit errors.
Digital Processing	Perform telemetry decommutation.* Display and convert telemetry channels data.
Data Transport	Ensure that communications are in place and functioning so that data can be routed to the project database and scientists.
Computer and Communication Administration	Implement and administer computer and communication systems.
Training	Train personnel on the processes and on the use of the ground data system.
System Engineering	Design a mission operations system that matches the requirements, takes constraints into account and has acceptable performance.

**Decommutation is the process by which a single telemetry signal is separated into its component signals.*

Saturn, gathering energy from two flybys of Venus, one flyby of Earth and one of Jupiter. Upon arrival at Saturn, the spacecraft will be placed into orbit around Saturn and a four-year tour of the Saturn system will begin.

The Huygens Probe will be delivered on the first (nominal) or second (backup) flyby of Titan. Multiple close Titan flybys will be used during the tour for gravity assists and studies of the satellite. The tour also includes icy satellite flybys for satellite studies and orbits at a variety of inclinations and orientations with respect to the Sun–Saturn line for ring, atmospheric, magnetospheric and plasma science studies.

Spacecraft and Payload

The Cassini spacecraft is a three-axis stabilized spacecraft. The Huygens Probe and the Orbiter instruments are affixed to the body of the spacecraft. There are 18 science instrument subsystems, which are divided into four groups: optical remote sensing; microwave remote sensing; fields, particles and waves; and Probe instruments.

Orbiter instruments that serve multiple investigations are called facility instruments. Facility instruments are provided by the Jet Propulsion Laboratory (JPL), the NASA Goddard Space Flight Center or by JPL and ASI. The facility instruments, except for the Ion and Neutral Mass Spectrometer (INMS), are operated by a JPL team called the distributed operations interface element.

Instruments that serve individual investigations are provided and operated by a Principal Investigator (the INMS is operated like a Principal Investigator instrument). The Huygens Titan Probe is operated from the Huygens Probe Operations Centre in Darmstadt, Germany.

Capabilities and Constraints

The Cassini–Huygens mission scientific objectives involve complex mission, spacecraft and payload demands. In addition, mission operations must fit within certain inherent constraints. However, operational capabilities built into the spacecraft can help to keep operations simple.

Operational Capabilities

Robustness. Robustness is provided by redundant engineering subsystem assemblies, healthy margins of Orbiter consumables and fault-protection software that provides protection for the spacecraft and the mission in the event of a fault.

Automation. Automation is provided by the onboard inertial vector propagator, which generates turn profiles, bringing the spacecraft from its last commanded attitude and rate to a possibly time-varying target attitude and rate. The target attitude is obtained by applying an offset to a base attitude, which is defined by primary and secondary pointing constraints as follows:

- Primary constraint — Align a spacecraft fixed vector (primary body vector) with a specified inertial vector (primary inertial vector).
- Secondary constraint — Align a spacecraft fixed vector (secondary body vector) with a specified inertial vector (secondary inertial vector).

Flexibility. Flexibility is provided by the capability of storing telemetry data on a solid-state recorder for later playback and by trigger-command capabilities. Most instruments operate from commands stored in their memories; a trigger command is issued from the central computer to initiate a preestablished series of instrument-internal commands.

Inherent Constraints

Cost. The major operational constraint of the Cassini–Huygens mission is that mission operations and data analysis activities must be conducted within fixed budgets (within both the U.S. and the European space communities).

Thermal. At Sun range closer than 2.7 astronomical units (AU), thermal constraints make it necessary to use the Cassini's high-gain antenna to shade the spacecraft from the Sun — except for infrequent turns away from the Sun (off-Sun turns), such as those used for trajectory correction maneuvers. The allowable duration of the off-Sun turns roughly scales with the square of the Sun range. For example, at 0.61 AU, the spacecraft could withstand a transient off-Sun duration of 30 minutes.

Telecommunications. While the high-gain antenna is used to shade the spacecraft, telecommunications mostly will be restricted to one of two low-gain antennas[1] and will proceed at very low bit rates (generally less than 40 bits per second).

Power. The electrical power from Cassini's radioisotope thermoelectric generators (676 watts at the beginning of the tour and 641 watts at the end of the tour) is not sufficient to operate all instruments and engineering subsystems simultaneously.

Data Rates. The bit rate available on the command and data subsystem data bus — which is limited to a total of 430 kilobits per second (kbps) — is not high enough to permit all instruments to output telemetry simultaneously at their maximum rates. Instruments and engineering subsystems also must share the number of bits stored on solid-state recorders and transmitted to the ground. During the tour, expected data rates are on the order of 14–166 kbps.

Pointing. The major pointing constraint arises from the fact that the instruments are fixed to the body of the spacecraft. Other pointing constraints prevent exposing sensitive spacecraft and payload components to undesirable thermal input. The pointing accuracy is two milliradians when the spacecraft is not rotating and pointing toward a fixed inertial direction. For target-relative pointing, the accuracy is limited by navigational uncertainties.

Navigation. During the tour, the spacecraft's orbit as a whole is controlled by Saturn's gravity. For satellite flybys, preflyby tracking is needed to support the maneuver that places the spacecraft in the final flyby trajectory. Postencounter maneuvers are required only for Titan as a result of its gravitational effect on the trajectory. A compromise must be reached to balance the desire to acquire science data during Titan's flyby with the desire of performing the post-encounter maneuver soon after closest approach in order to minimize the amount of propellant used for that maneuver.

Propellant. This is the principal consumable of the mission. At launch, the spacecraft will carry 2919 kilograms of bipropellant for the main engine and 132 kilograms of hydrazine for the thrusters. Once the bipropellant is gone, no significant maneuver can be planned (unless significant leftover hydrazine is used). Once the hydrazine is gone, the spacecraft will begin to lose attitude control. For this reason, propellant budgets are subject to particular scrutiny.

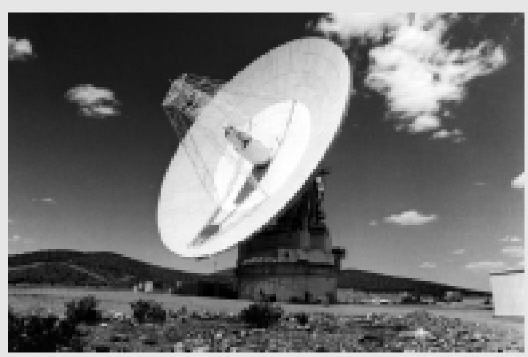
The Probe. After separation from the Orbiter, the Probe will be powered by five batteries. After 22 days of coasting, there will be enough power to operate the Probe for three hours from entry, including two and a half hours of descent and 30 minutes on the surface. The data rate over the Probe–Orbiter link will be 16 kbps. During cruise, Probe checkouts must be performed to verify the capability of executing the Probe mission. The checkouts simulate as closely as possible the sequence of activities to be performed when the Probe approaches Titan.

BRINGING IMAGES FROM SPACE TO EARTH

NASA brings us unforgettable images of space. In addition to their enormous scientific value, these images dazzle and capture our imagination. Bringing images from space to Earth – in effect, doing long-distance photography – is a complicated process that depends on our ability to communicate with spacecraft millions of kilometers from Earth. This communication is the responsibility of NASA's Deep Space Network (DSN), a global system of powerful antennas.

Taking the picture is the job of the spacecraft's imaging system: digital camera, computer and radio. Reflected light from the target – for example, Saturn's rings or the large satellite Titan – passes through the lens and one or more color filters before reaching a charge-coupled device (CCD). The surface of the CCD is made up of thousands of light-sensitive picture elements, or "pixels." Each pixel assigns a number value for the light it senses; the values are different for each color filter. The spacecraft's computer converts the data into digital code – bits – which are transmitted to Earth. The bit stream is received by huge antenna receivers at one of the three DSN sites: Goldstone, California; Canberra, Australia; and Madrid, Spain. The data are then sent to JPL in Pasadena, California, where the bits are reformatted, calibrated and processed to ensure a true representation of the target, then recorded on high-quality black-and-white or color film for archiving and distribution.

Of course, the DSN must handle not only image data but all the other kinds of data Cassini transmits to Earth as well. For flexibility, Cassini will use a variety of antenna configurations – 34-meter, 70-meter or an array of 34- and 70-meter dishes.



Operational Choices

The following operational choices were made to reduce costs and simplify mission operations.

Limited Science

To reduce costs, there is no plan to acquire science data during inner and outer cruise phases. The only exception is a gravitational wave experiment which, following the Jupiter flyby, will attempt to detect gravitational waves emitted by supermassive dynamical objects such as quasars, active galactic nuclei or binary black holes.

Science data will not be collected during the planetary flybys[2] except for calibrations of the Cassini Plasma Spectrometer, the Dual Technique Magnetometer and the Magnetospheric Imaging Instrument at Earth, and calibration of the Radio and Plasma Wave Science instrument at Jupiter. Other science activities during the inner and outer cruise phases will be limited to deployments, maintenance, characterizations and checkout. Science observations will begin two years before Saturn orbit insertion.

Limited Operational Selections

To simplify operations, the number of allowable operational selections in several areas of mission operations has been reduced to a limited set of configurations.

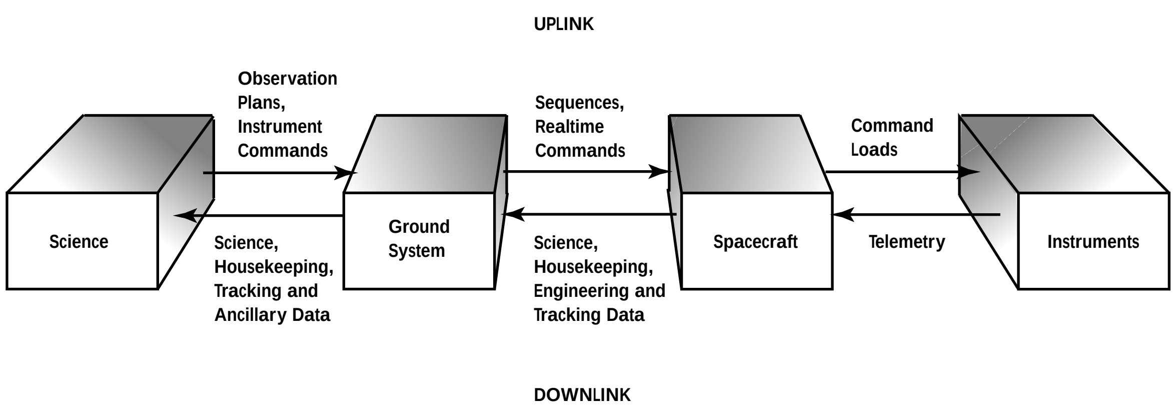
Telemetry Modes. A set of telemetry modes has been defined to provide rates for recording data on the solid-state recorder and for downlink in the context of changing telecommunication capabilities. Each telemetry mode represents a unique configuration of data sources, rates and destinations for telemetry data gathered and distributed by the command data subsystem. There are five types of telemetry data: engineering, science housekeeping, scientific, playback from the solid-state recorder, and Probe. The telemetry modes are grouped into nine functional categories. The three primary modes for operations during the orbital tour are realtime engineering, science and engineering record and realtime engineering and science playback.

Operational Modes. The concept of operational modes was invented to reduce operational complexity arising from the facts that there is insufficient power to operate all the instruments simultaneously, and that all the instruments cannot be optimally pointed in a simultaneous fashion because they are fixed to the body of the spacecraft.

The operational modes concept prescribes that instruments will operate in a series of standard, well-characterized configurations. Each operational mode is characterized by the state of each instrument (for example, “on,” “off,” “sleep,” etc.); minimum and maximum power and peak data rate allocations for each instrument, and states of certain engineering subsystems: the radio frequency subsystem, the solid-state recorder, the attitude and articulation control subsystem and the propulsion module subsystem.

W H A T G O E S U P . . . M U S T C O M E D O W N

This diagram shows the uplink and downlink data flow process. (Housekeeping data provide information about science instruments.)



During much of Cassini's orbital tour, 15 hours in an optical remote sensing mode will alternate with nine hours in a fields, particles, waves and downlink mode. Other modes will be used for radar and radio science observations. Instruments that are not collecting data are generally left in a low-power sleep state, so as to reduce on–off thermal cycling, keep high voltages on and avoid reloading instrument memories each time they need to operate.

Basic Mission. This concept prescribes that 98 percent of the tour will be conducted with a small number of reusable multi-instrument sequence modules and templates. The remaining two percent (seven days a year) may consist of unique sequences. These sequence constructs are defined as follows:

- A module is a reusable science sequence of commands integrating system-level and trigger commands, pointing functions and telemetry mode selections.[3]
- A template is a sequential series of fixed-duration modules, fixed sequences, gaps of fixed durations or other templates whose relative timing is set.
- A fixed sequence is of fixed duration and is designed and validated once for multiple uses, does not use operational modes and has a fixed list of variable inputs.
- A unique sequence has a specific purpose, is used once and does not use modules.

Data Return. Deep Space Network (DSN) coverage of Cassini during the tour will consist of one pass per day, with occasional radio science passes. To reduce operational complexity, the coverage is divided into high-activity and low-activity days, with four gigabits or one gigabit of data returned per day, respectively. A quarter of each orbit, or seven days, whichever is less, will be considered high-activity.

To simplify operations while maintaining some flexibility for data gathering, three configurations for data return have been selected. They differ essentially by the DSN antennas used (34-meter antennas, 70-meter antennas or 34-meter and 70-meter antennas arrayed) and the durations of the passes.

Tour Maneuvers. Propulsive maneuvers during the orbital tour will generally occur three days before and two days after each Titan flyby, near apoapsis (the farthest point in the spacecraft's orbit).

Workforce Management

Distributed Operations. Distributed operations places observing decisions, including generation of instrument-internal subsequences, in the hands of the science teams. The implementation of distributed operations for the Cassini mission is achieved through computers, computer-resident software and communication lines provided by JPL to the remote sites, as well as science participation in the uplink (mission planning, sequence development) and downlink (Principal Investigator instrument health monitoring) processes.

Virtual Teams. Cassini uses virtual teams for mission planning and sequence development. These teams bring together people for the development of a given product. Their membership varies, depending on the particular subphase or sequence to be developed. Each virtual team member maintains membership in his/her mission team of origin and continues to work for that team while providing expertise to and generating products for the virtual team.

Cassini–Huygens will launch on October 6, 1997, from Cape Canaveral in Florida, aboard a Titan IVB/Centaur launch vehicle.

Uplink Processes

Cassini mission operations uses five uplink processes: science planning, mission planning, sequence development, realtime command development and radiation.

Science Planning

The purpose of the science planning process is to plan conflict-free science activities. During the inner and outer cruise phases, the science planning process is particularly simplified because the acquisition of science data is limited to deployments, maintenance, calibrations, checkout and the gravitational wave experiment.

In preparation for the science cruise phase and the tour, Cassini scientists will prepare a science operations plan. The science office and the four discipline working groups — atmospheres, magnetospheric and plasma science, rings and satellite surfaces — will play a major role in coordinating this effort.

Mission Planning

The mission planning process is the responsibility of the mission planning virtual team. This process focuses on particular subphases of the mission and consists of two subprocesses: mission plan and mission phase plans updates, and phase update package generation.

Mission Plan and Mission Phase Plans Updates. The mission plan is the principal reference for a high-level description of the Cassini–Huygens mission. It documents spacecraft design and trajectory, mission phases, high-level activities and operational strategies for collection of scientific and engineering data. The plan serves as a common starting point and a guide for the implementation of mission operations.

Mission phase plans describe specific mission phases. Examples include the "Cassini Spacecraft System Maintenance, Calibration and Deployment Handbook," which identifies those activities listed in the document's title as well as other "one-time only"[4] or science activities of the inner and outer cruise phases, and the Cassini Inner Cruise Activity Plan, which describes all spacecraft activities from two days after launch until the end of the inner cruise phase. These plans are updated for a given mission subphase to provide levels of detail adequate for implementation. Changes in spacecraft performance or in ground capabilities may make it necessary for the mission planning virtual team to perform trade studies and mission analyses.

Phase Update Package Generation. This activity consists of translating the updated sections of the plans into a set of inputs, called a Phase Update Package, for the sequence development team(s). A major portion of this task consists of developing timelines for each sequence of the mission subphase. Activities contained in those timelines include spacecraft events, geometric events, data rates, solid-state recorder strategies and DSN allocations, with a resolution time between one hour and one day.

Sequence Development

The sequence development process is the responsibility of the sequence virtual team. This process focuses on particular sequences and consists of three subprocesses: activity planning, subsequence generation and sequence integration and validation.

Activity Planning. The sequence timeline is refined to one-minute resolution. Inclusion of the latest DSN allocations, revisions arising from the verification of resource allocations and other revisions such as timing changes are included in the timeline. The timeline is verified for compliance with activity level mission and flight rules and constraints.

Subsequence Generation. Science, engineering, system-level and ground-event subsequences are implemented to the command level. The subsequences are generated by the appropriate teams. For instance, the team known as the flight system operations element generates the subsequences for activities, the distributed operations interface element generates the subsequences for the facility instruments, the Orbiter Principal Investigator teams generate the subsequences for their instruments and the Huygens Probe Operations Centre commands the Probe (prior to its separation from the spacecraft).

Sequence Integration and Validation. The set of subsequences is merged into an integrated sequence. The sequence virtual team leader verifies that the syntax is correct and that mission and flight rules and constraints are not violated. There may be a need to validate the sequence through simulation, which can be done in the Cassini high-speed simulator or in the Cassini integration test laboratory.

The high-speed simulator is a high-fidelity simulator of the command data subsystem and attitude and articulation control subsystem's computers. The integration test laboratory contains hardware identical to hardware flown on the spacecraft, in particular the command and data subsystem, solid-state recorders, attitude and articulation control subsystem's computers, sensors and actuators.

Realtime Commands

A realtime command is one that is generated and transmitted subsequent to the nominal sequence development process. It can be executed immediately after receipt by the spacecraft or its execution may be delayed. There are several types of realtime commands. Some are planned and pregenerated, and are used for repetitive transmissions. They are not part of the sequence, but the sequence contains a window to send the realtime command if needed. Some realtime commands are planned but not generated, and are generally used for updating parameters. The need to change the parameter value is known, but the value to which it should be changed is not. Realtime commands that are unplanned, with varying degrees of time criticality, are emergency commands.

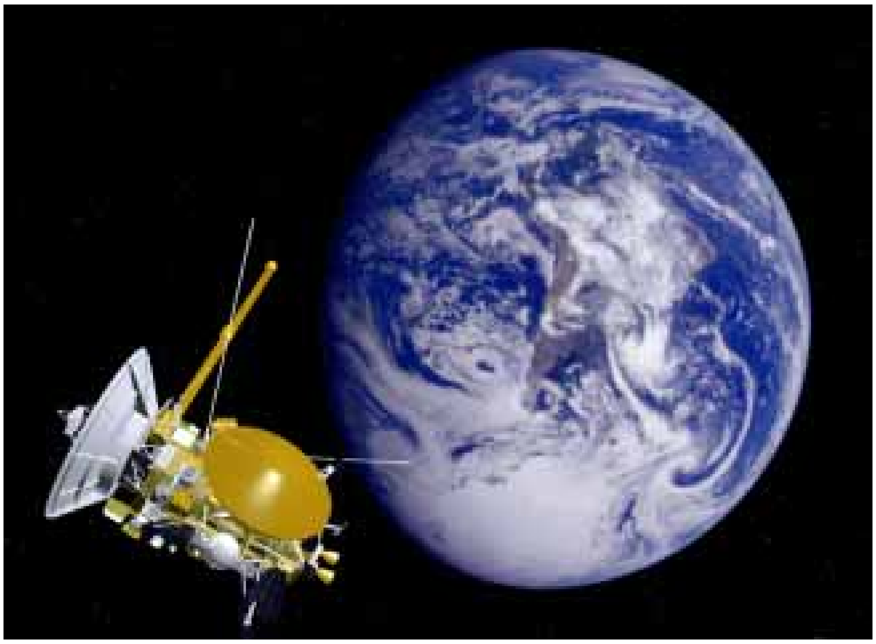
System-level realtime commands are handled by the sequence virtual team. There is a plan to have instrument-internal realtime commands handled automatically after the requester has generated, verified and delivered the realtime command file to the project's central database.

Radiation

After translation into appropriate format by a JPL team called the realtime operations element, sequence and command files are sent or "radiated" to the spacecraft by a DSN antenna.

Downlink Processes

Cassini–Huygens mission operations use six downlink processes: realtime data processing, data storage and



The flyby of Earth in Cassini–Huygens' primary trajectory occurs on August 16, 1999, 57 days after the second Venus flyby. This artist's rendition shows the spacecraft over South America.

distribution, realtime monitoring, nonrealtime data analysis, science data analysis and science data archiving.

Realtime Data Processing

A deep space station antenna acquires the signal transmitted by the spacecraft, passes it through a low-noise amplifier, which boosts the energy level of the signal, and distributes it to the signal processing center.

In the signal processing center, the signal goes through a receiver, where it is converted into an electrical signal and the subcarrier is separated from the carrier. (The carrier, which is the main component of the radio signal, is modulated with information-carrying variations; the subcarrier is a modulation applied to the carrier.) The receiver distributes the subcarrier and the tracking data to separate assemblies. In the telemetry string, the telemetry is separated from the subcarrier and digitized, the digitized encoded data are corrected to eliminate bit errors (loss of information by a change in value of a bit by some chance effect) and they are blocked into frame-size records.

The full records are then routed via the ground communication facility interface to the telemetry input subsystem, where science, instrument housekeeping and engineering data are separated. The realtime operations element operates the telemetry input subsystem.

Data Storage and Distribution

The science packets and instrument housekeeping and engineering channelized data are stored on the telemetry delivery system. Selected data are broadcast for realtime monitoring and displayed by the data monitor and display program. For non-realtime analysis, data are obtained through queries of the telemetry delivery system.

Realtime Monitoring

The mission controllers, engineering teams and science teams monitor telemetry and look for anomalies in real time. They process the channelized data, looking for evidence of anomalous behavior, displaying the data in various ways and performing special processing.

Non-Realtime Data Analysis

The flight system operations element retrieves engineering data used to determine the health, safety and performance of the spacecraft, and processes the tracking data to determine and predict the spacecraft's trajectory. The team generates ancillary information that is delivered to the project central database.

The distributed operations interface element for the facility instruments, the Principal Investigator teams for their instruments and the operations team for the Probe process the data, converting telemetry and raw tracking data into products usable for verification that planned activities have been performed as expected and of instrument health and safety evaluation and science data analysis.

Science Data Analysis

The Cassini science team members and the interdisciplinary scientists (who use scientific information from two or more instruments provided by science teams) are responsible for this process. Science data analysis is the process by which scientific studies using the data products are conducted to evaluate the information content of the measurements, characterize physical phenomena, identify causes and effects, appraise existing theories and develop new ones — and produce highly processed data and publications to increase and disseminate scientific knowledge.

Science Data Archiving

This is the process by which data are recorded and stored in approved national data archives for future references and scientific studies.

FOOTNOTES

[1] At approximately 14 months after launch, the Earth–spacecraft–Sun angle will be small enough to allow use of the high-gain antenna for telecommunications. That 25-day period will be used for a checkout of all the Orbiter instruments. This will be the first real opportunity after launch for the science teams to verify that their instruments are working properly.

[2] Science at Jupiter is currently not planned, but is not precluded.

[3] The inertial vector propagation and trigger command capabilities are key to enabling the implementation of modules.

[4] An example of a one-time only activity is the launch plus 14 months Orbiter instrument checkout.